Simulation of 3D-Silicon Sensors for the TIMESPOT project

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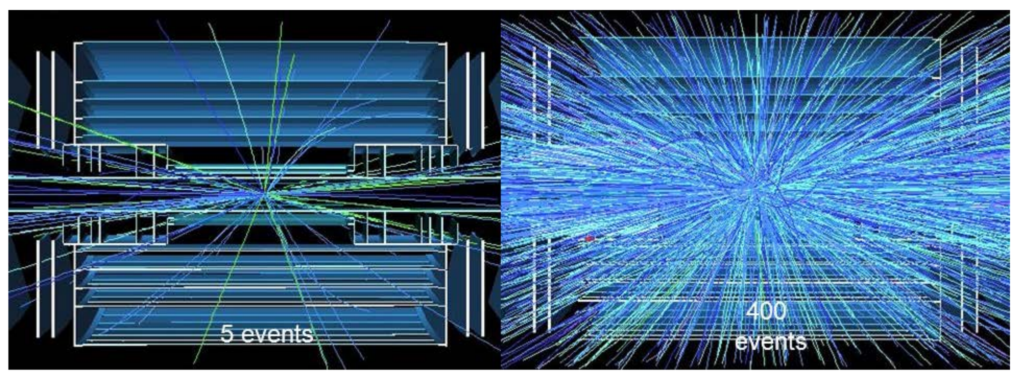
Introduction

In future High Luminosity Large Hadron Collider (HL-LHC) experiments planned over the next 10 years, the number of collisions per unit of time is expected to increase by more than a factor of 10 **[fig. (a)]**. The TIMESPOT project, a INFN-financed initiative, is focused in the development of a space and time (4D) tracking detector which will be capable of operating in those conditions. The device will have a resolution around 50 µm in space and lower than 50 ps in time and a high radiation resistance up to several 10^{16} 1 MeV. The project consists of 6 work packages (WP), each of them focused in the development of one component of a Hi-Lumi (HL) tracker. WP1 and WP2 are respectively focused in the design and simulation of 3D-type silicon and diamond sensor optimized for timing. WP3 deals with the development of a fast front-end electronic based, for the first time for this kind of applications, on a 28 nm CMOS technology. The WP4 activity is aimed to study and development of fast tracking algorithms and WP5 if focused in the design and implementation of fast readout data boards. The development, assembly and final test of the prototype, which will combine all the products of the first 5 WPs, is up to WP6. This paper describes the activity linked to the silicon sensor design and simulation and shows first results.



↑ Difference between low luminosity and high luminosity experiments at LHC. For high luminosity experiments, reducing pile-up becomes an important issue (a)

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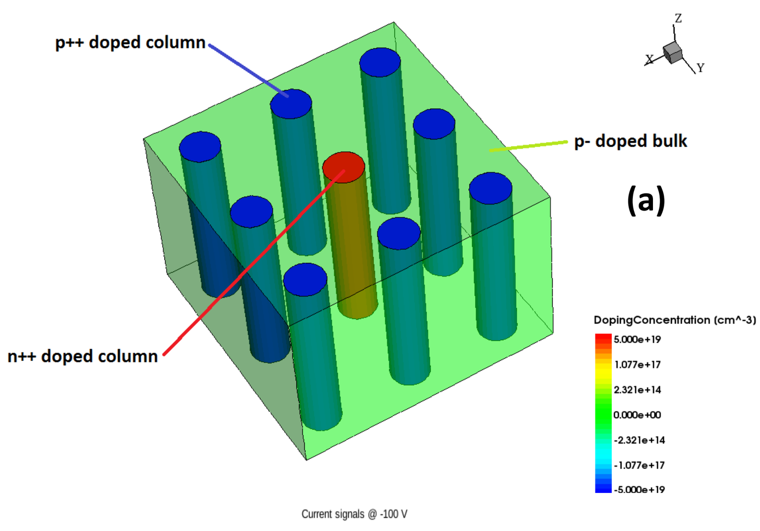
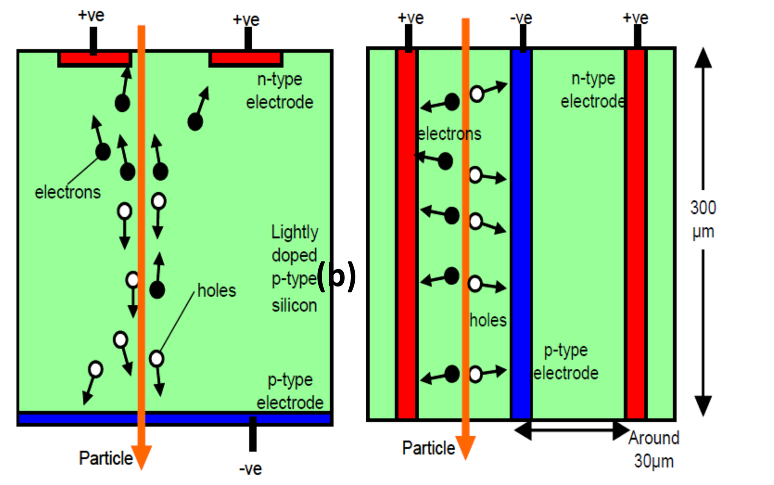
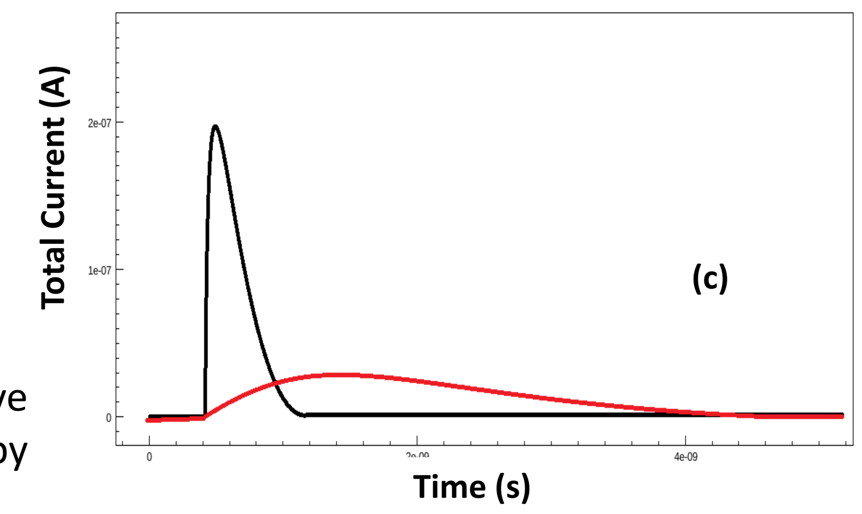
3D sensors

The main feature of 3D silicon sensors **[1]** is the geometrical configuration of their electrodes, which are oriented perpendicularly to the wafer surface and penetrate deep inside the substrate **[fig. (a)]** (up to hundreds of µm). This approach allows to decouple interelectrode space from the sensor thickness with positive implications for sensor in terms of: 1) Lower depletion voltage; 2) Higher radiation hardness; 3) Faster charge collection







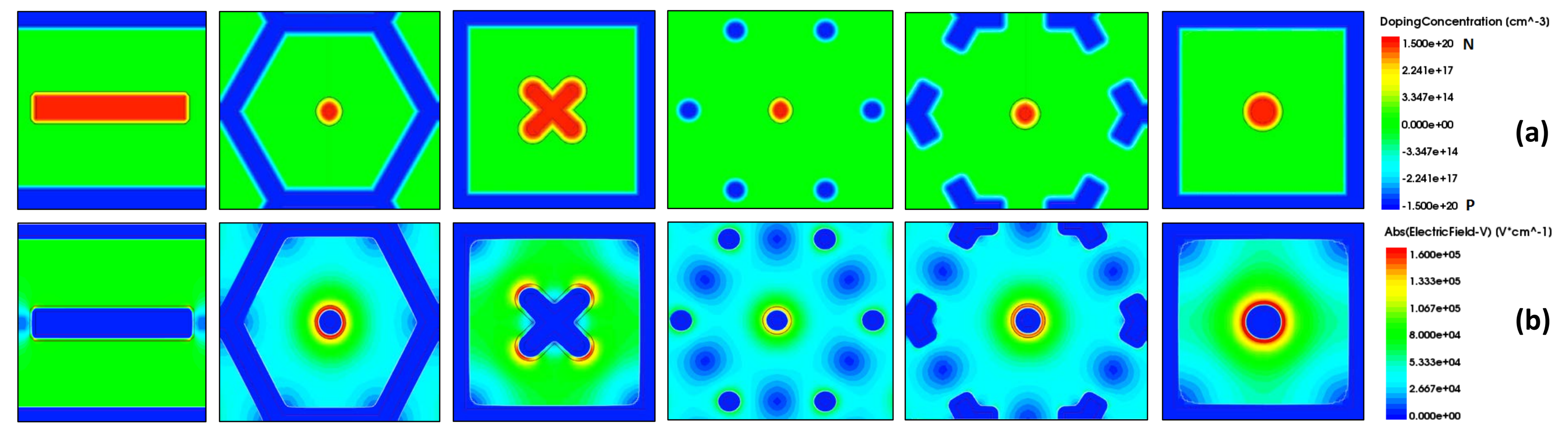
Compared to a classical planar sensor with same active width, a 3D sensor can collect charge clearly faster by simply setting the electrodes close to each other

[1] Sherwood I. et al. , "**3D: A New architecture for solid state radiation detectors**" - ParkerNucl.Instrum.Meth. A395 (1997) 328-343 UH-511-839-96

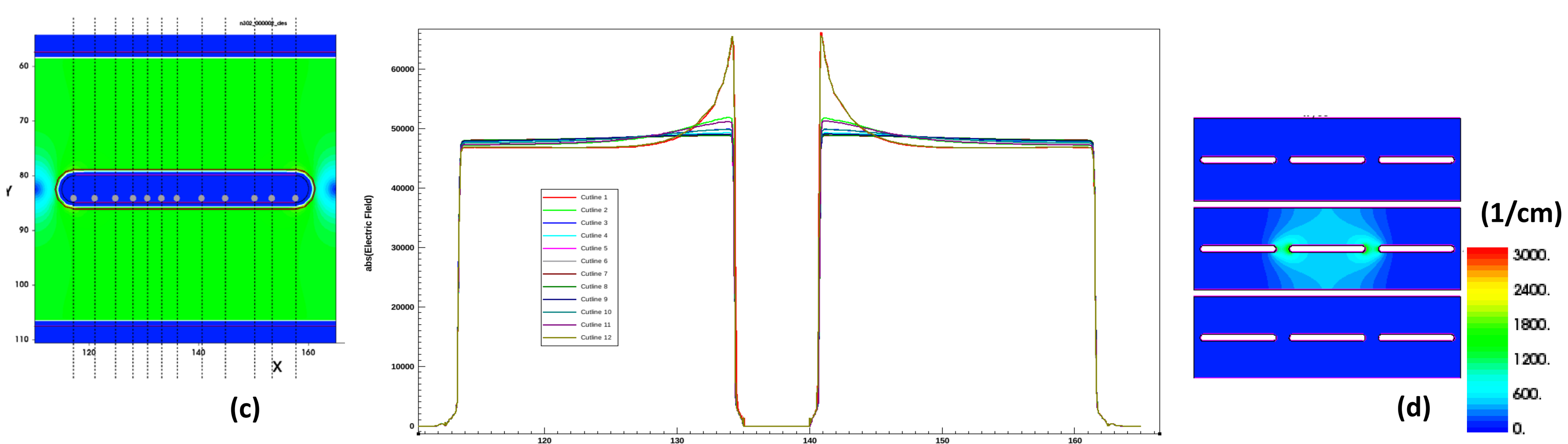
Pixel Geometry

The technological features of the 3D sensor technology **are not immediately applicable for fast timing tracking** as the electrode configuration influences sensibly signal response.

A **first design study of the geometric configuration of the electrodes** was performed using the Sentaurus TCAD environment. 2D models representing different electrode configurations **[fig. (a)]**, have been modelled and the electric field over all the area was simulated **[fig. (b)]** . A selection concerning electric field uniformity and the extension of low field areas at 100 V bias was done.



The chosen solution is the electrode configuration with 3 parallel trenches: one central diode trench (n+) and two resistive trenches (p+) for electric field bias. The pixel pitch is 55 x 55 µm² in order to be compatible with the TIMEPIX family **[2]**. The electric field results uniform over most of the area of the pixel, with small exceptions in the areas between the diode trenches **[fig. (c)]** .

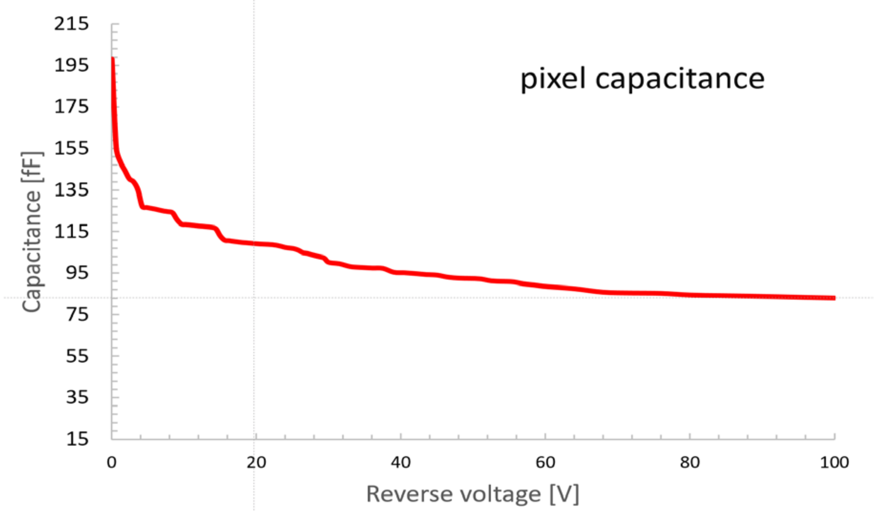


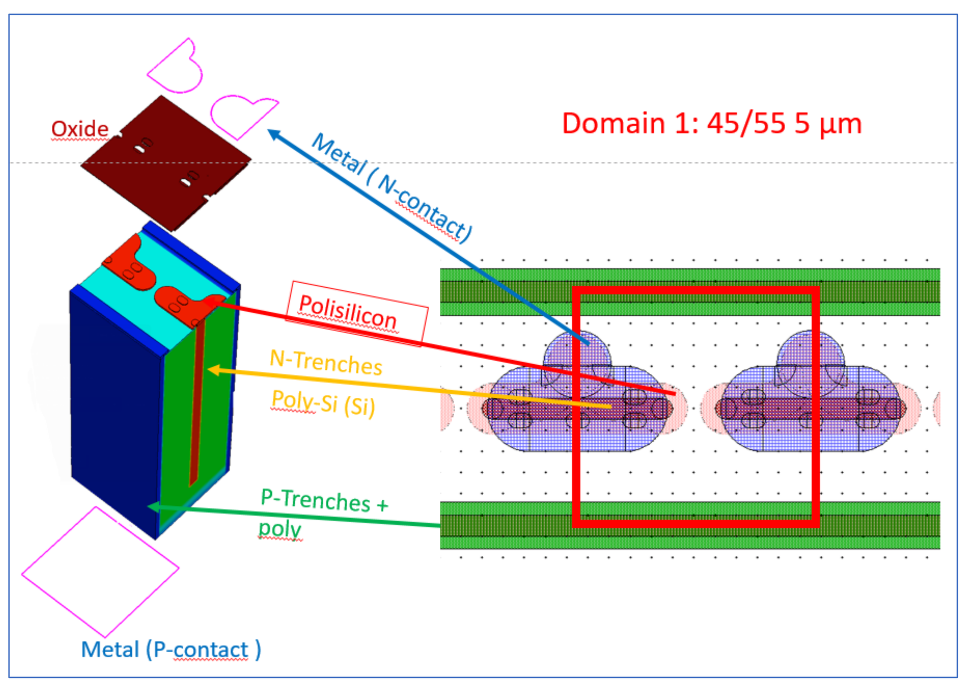
Weighting field of a 3x3 pixel matrix was also simulated, discovering that the weighting field of a single pixel is bounded only inside a single pixel line and does not extends over the bias trenches **[fig. (d)]** .

[2] *chern.ch/medipix*

3D model and first electrical characterisations

The selected configuration has then been reproduced in a complete 3D model, considering a diode trench depth of 135 um. Design includes also some optimizations to reduce the capacitance of the sensor and first bump bonding pads are designed.



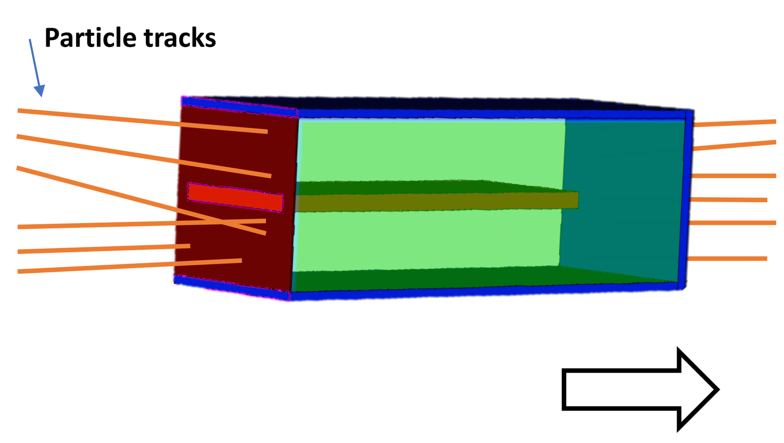


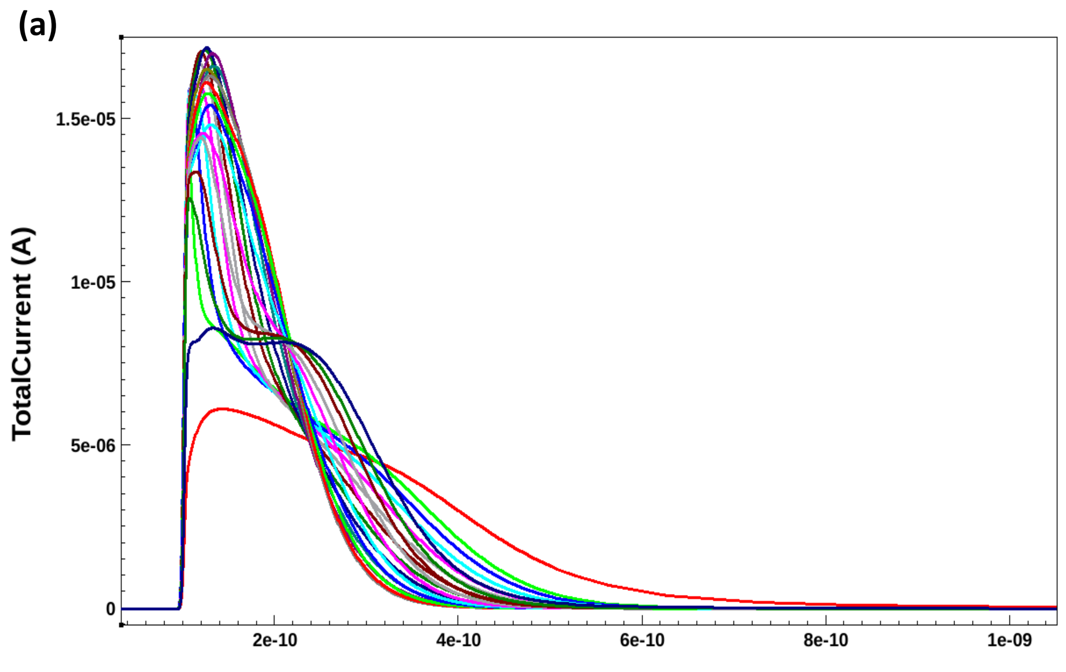
Capacitance was simulated using small signal analysis, resulting below 100 fF/pixel for bias voltages above 50 V.

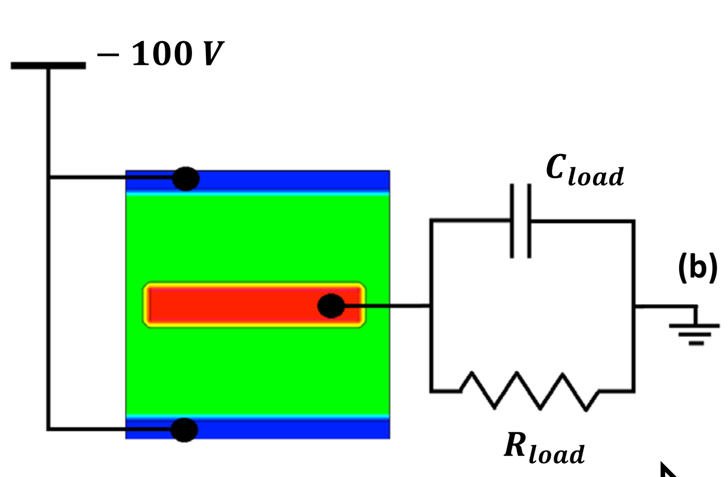
Sensor operation (TCAD)

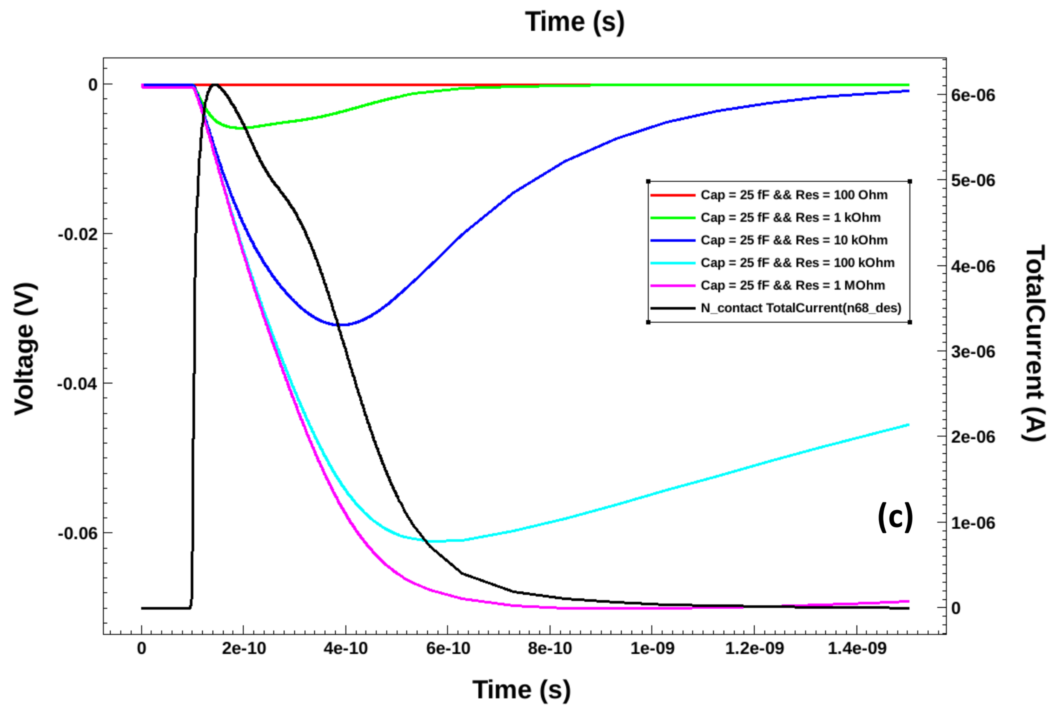
TCAD

Sensor response is currently simulated in order to study the output signals generated by the sensor when crossed by a high energy particle. Tracks are randomly generated in order to collect a wide variety of signals, which will be used to get first information about the performances of the sensor **[fig. (a)]**.





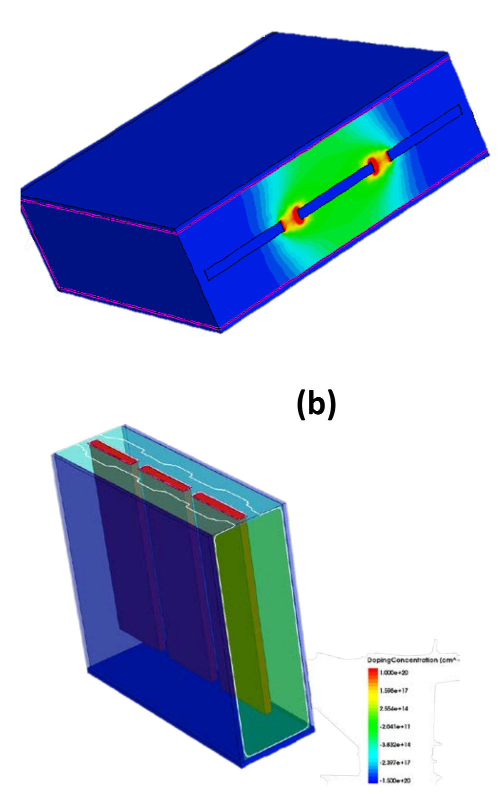


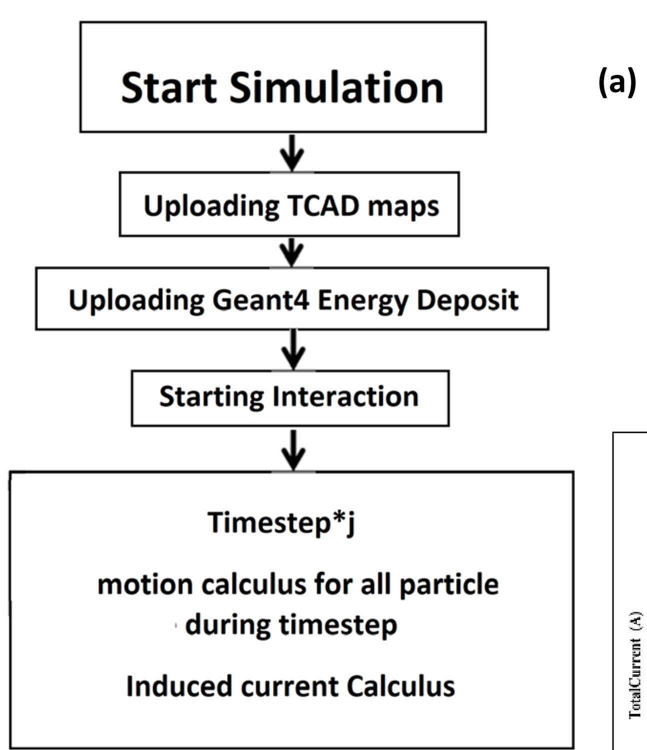


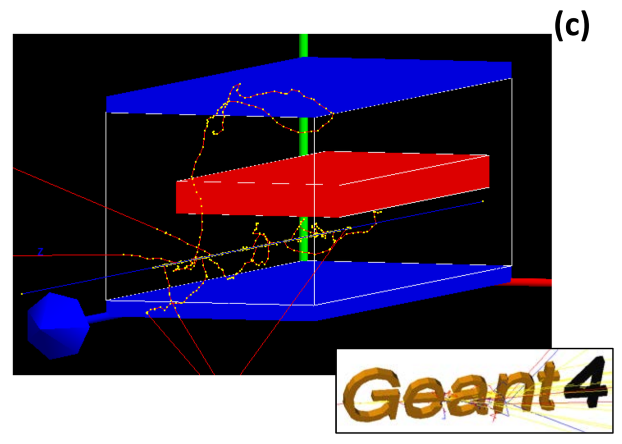
A second simulation run including a simplified load, is also simulated **[fig. (b)]**. Scenarios includes resistance spacing from 10 Ω to 1 GΩ **[fig. (c)]** and capacity spacing from 10 fF to 50 fF. Observed risetime is below 100 ps, and amplitude is over 5 mV.

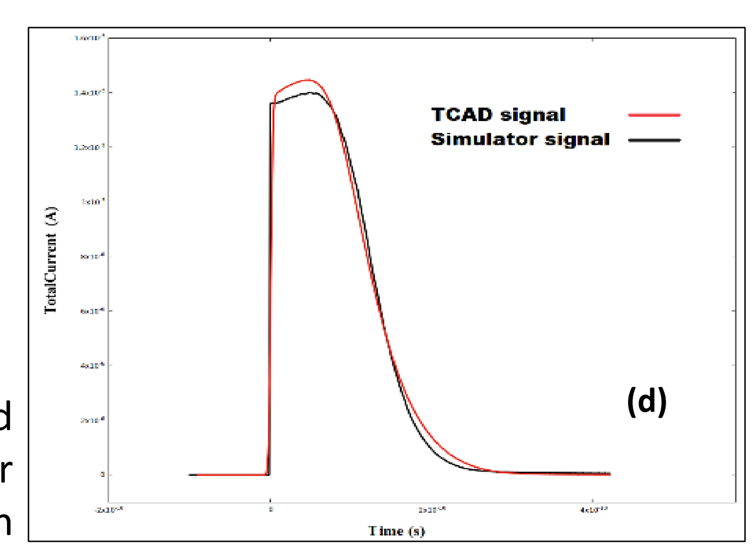
Self standing signal simulator

Using TCAD to generate a large number of signals is problematic owing to extremely large computation time and inefficiency in accumulating sufficient statistics (average CPU simulation time for a 24 core system is 30 hours for one single signal). To overcome this problem, a self-standing simulation model, is under development **[simulation flow in fig. (a)]**.









The simulator generates current signals by using electric field and mobility maps from TCAD **[fig. (b)]** and particle-sensor interaction information from Geant4 **[fig. (c)]**. Signal formation is calculated, applying the Ramo theorem **[3]**.

$$i = -q\overrightarrow{v(t)} * \overrightarrow{E_w}$$

First tests show simulated signals with shape close to the ones simulated by TCAD, but with an average computing time less than 2 minutes per single signal **[fig. (d)]**.

Future steps will include GPU multithreading, using the Nvidia CUDA Toolkit based Hydra Multithreading data Analysis Framework.

[3] S. Ramo (1939), "**Currents Induced by Electron Motion**", in Proceedings of the IRE, vol. 27, nº 9, 1939, pp. 584–585